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RESEARCH MEMORANDUM

COMPARISON OF EFFECT OF A TURBOJET ENGINE AND THREE COLD-FLOW CONFIGURATIONS ON THE STABILITY OF A FULL-SCALE SUPERSONIC INLET

By Norman T. Musial

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

[redacted]

NATIONAL ADVISORY COMMITTEE
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COMPARISON OF EFFECT OF A TURBOJET ENGINE AND THREE COLD-FLOW CONFIGURATIONS ON THE STABILITY OF A FULL-SCALE SUPERSONIC INLET

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SUMMARY

Comparisons were made at a Mach number of 2.0 and an angle of attack of 0° between the inlet stability achieved with a turbojet engine and three cold-pipe configurations behind the same supersonic inlet.

Inlet stability was affected by the position of the airflow regulating device behind the inlet. Close approximation of the inlet stability limit of the J34 engine-inlet configuration was obtained by a cold-pipe inlet configuration having a length and volume approaching that measured to the engine turbine. Volume and pipe-length-to-choke-point appeared to have a negligible effect on the inlet pressure-recovery - mass-flow curve at a cowl-lip-position parameter of 42.6° and, within the accuracy of the data, had only a small effect on the minimum subcritical stable mass flow below a cowl-lip-position parameter of 44° (conical shock angle, 42.6°). Going from a short to a long cold-pipe configuration decreased the initial buzz frequency at the cowl-lip-position parameter of 42.6° and increased the minimum value of this parameter for complete buzz-free operation.

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INTRODUCTION

Wind tunnel tests of supersonic inlets are usually made under cold-flow conditions, and such tests are generally believed to simulate properly the actual conditions at which the inlet must operate. Parameters of inlet performance such as pressure recovery and inlet stability data thus obtained are often directly applied to the full-scale flight configuration.

Recent experience with a full-scale installation (ref. 1) suggests that although little noticeable effect is observed on pressure recovery, there is some difference in inlet stability between a cold-flow installation and an installation combining the inlet with a turbojet engine. Obviously, any such difference is significant, and attempts should be made to understand its origin and predict its magnitude.

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After the study of reference 1, it was hypothesized that the volume (based on the plenum chamber behind the inlet to the flow throttling device) and surface flow area (damping factor) behind the inlet influenced the dynamic behavior of the system. It was further hypothesized that such differences did exist between the cold-flow and engine configurations of reference 1 and were responsible for the discrepancies in the stability results observed.

Tests were therefore undertaken to confirm these hypotheses. The same inlet described in reference 1 was tested with three separate cold-flow configurations behind the inlet, each representing a change in plenum-chamber volume and damping coefficient. Also, additional data were obtained with the inlet-J34 engine configuration. The data were taken in the 8- by 6-foot supersonic wind tunnel at the Lewis laboratory at a free-stream Mach number of 2.0 and an angle of attack of 0°.

SYMBOLS

m mass flow, slugs/sec

P total pressure, lb/sq ft

θ_l cowl-lip-position parameter defined as angle between axis of spike and line joining cone apex and cowl lip

θ_s conical shock angle defined as design angle of oblique shock on lip (42.6°)

Subscripts:

0 free stream

3 compressor face or diffuser exit

APPARATUS AND PROCEDURE

Sketches of the cold-flow and inlet-engine configurations evaluated are shown in figure 1. For the cold-flow case a fixed-orifice - movable-plug system was employed to vary inlet airflow. The plenum-chamber volume and damping factor behind the inlet could be changed by varying the position of the orifice-plug combination. The arrangement conventionally employed in cold-flow inlet testing is shown in figure 1(b). This configuration is called herein the "long-pipe" configuration. For purposes of comparison, the inlet-engine configuration is shown to scale in figure 1(a).

As can be seen in figures 1(c) and 1(d), the removal of the converging nozzle and insertion of an orifice-plate - axially movable-plug system enables the position of the choked-flow station behind the diffuser to be changed. Two such positions were investigated. The "medium-pipe" configuration (fig. 1(c)) represents a length about equal to the turbine location in the inlet-engine configuration. The "short-pipe" configuration (fig. 1(d)) represents a length about equal to the third-stage compressor location.

The inlet was equipped with a translating conical spike having a 25° half-angle. The tip projection could be remotely varied with a hydraulically actuated servomechanism. The cowl-lip-position parameter θ_l could be determined to an accuracy of ±0.1°. The variation of diffuser area over the range of θ_l is given in figure 2.

Dynamic pressure pickups were located at several longitudinal stations in the nacelle inlet in order to detect initiation and frequency of pulsation.

For all cold-flow configurations, the minimum subcritical inlet stability curves were obtained in the following manner. For each θ_l, the plug was moved to reduce mass flow through the configuration until the inlet as observed by schlieren and dynamic pressure pickups just started to buzz. The plug position was noted, the plug was backed off, and then extended as closely as possible to the previous position without actually putting the inlet into buzz. The minimum subcritical stability curve with the engine installed was similarly obtained. In this latter case, however, the mass flow was changed by varying the engine speed rather than the plug position.

The subcritical inlet mass flow for all configurations was calculated by area-weighting the total-pressure tubes at station 3 (diffuser exit). The mass-flow values thus obtained are believed accurate to ±3 percent.

RESULTS AND DISCUSSION

Complete inlet performance curves for all four configurations were not obtained. The inlet performance curves for the long-pipe and engine configurations from reference 1 are reproduced in figure 3. Points for the short- and medium-pipe configurations at the same θ_l of 42.6° and a Mach number of 2.0 are also included. The tailed symbols indicate inlet pulsing.

These data indicate that the pressure-recovery - mass-flow curve at a Mach number of 2.0 and a θ_l of 42.6° is essentially the same for both engine and long-pipe configurations. In addition, the data available for the short and medium cold-pipe configurations also show no significant effect of duct volume, surface area, and length on diffuser pressure recovery. The small scatter in these data is believed due to experimental error.

The minimum subcritical stability limits as a function of θ_l are presented in figure 4. Figures 4(a), (b), (c), and (d) are the individual plots of the engine, long-, medium-, and short-pipe configurations, respectively. Figure 4(e) is a summary plot of the four configurations. The area under the curve represents unstable inlet operation. Increasing θ_l by retracting the spike enables all configurations eventually to reach a point of complete stable subcritical operation. It appears that at a free-stream Mach number of 2.0 and below a θ_l of 44°, volume, surface and flow areas, and length-to-choke-point have only a small effect on the minimum stable mass flow. At a free-stream Mach number of 2.0 the design θ_l is 42.6°. These results are, therefore, consistent with those in reference 2 at a slightly lower Mach number and with a small-scale model.

The data do reveal, however, that some aspects of the dynamic diffuser behavior are influenced by the configuration behind the inlet diffuser. The initial pulse frequency (frequency at first indication of steady inlet pulsing) at $\theta_l = \theta_s$ and the mass-flow stability limits at $\theta_l > 44^{\circ}$ showed considerable dependence on configuration. At a θ_l of 42.6° initial frequencies increased from 8 cps for the long pipe to 16.9 cps for the short pipe. Initial frequencies for the medium-pipe and engine configurations were 13.8 and 16.2 cps, respectively. Thus, it appears that considering initial pulse frequency only, the engine installation was best simulated by the short-pipe, cold-flow configuration.

With a given cold-pipe configuration and the inlet pulsing, the amplitude remained essentially constant along the length of the duct.

The value of θ_l at which complete subcritical inlet stability was achieved increased noticeably with increases in pipe length. However, even with the short pipe, complete subcritical stability was achieved only at $\theta_l \geq 44^{\circ}$, a condition at which the oblique shock generated by the spike falls inside the cowl lip ($\theta_s = 42.6^{\circ}$). It appears from the the data that the θ_l stability limit for the engine configuration approaches the medium cold-pipe configuration which has a length and volume equivalent to that represented by assuming that the choke point occurs at the engine turbine.

It becomes apparent, therefore, that considerable care must be exercised in determining and evaluating inlet stability data, because full-scale flight results may depart considerably from those obtained with a cold-flow model and may even depart from full-scale flow tests. To evaluate the source of the differences for the case at hand, a study of the model configurations is in order.

Some of the pertinent physical characteristics of the four configurations tested are tabulated in tables I and II. Volume, surface area, and length-to-choke-point increased progressively in going from the short-, to the medium-, to the long-pipe configuration. The engine-inlet combination has a pipe-length-to-choke-point (defined as the exit nozzle) greater than the long pipe and a volume approximately equal to that of the long-pipe configuration. It is, therefore, interesting to note that although it appears that the physical characteristics of the long pipe best simulate the engine configuration (see tables I and II), poor agreement for both θ_l stability and dynamic behavior is obtained between these configurations. The data of figure 4(e) indicate that the inlet stability of the engine configuration actually falls between that of the short and medium pipes. The engine physical characteristics approximating the shorter duct lengths are the volume and length to the compressor exit.

This observation is consistent with the results reported in reference 3 which indicate that an inlet pulsation is damped considerably in going through the compressor of the J34 engine. Pressure amplitudes propagated through the flow system were reduced from 22 percent of the local total pressure at the diffuser inlet to about 5 percent at the compressor exit. If the compressor exit of the J34 engine is assumed analogous to the choke position of the cold-pipe configurations, then the duct volume as well as the damping exerted behind the compressor exit would exert a negligible effect on the initial pulse frequency and inlet stability limit. Though there may be other factors to consider, the volume and duct length to the compressor exit may be sufficiently representative to allow selection of a cold-pipe configuration which will duplicate with reasonable accuracy the dynamic and stability behavior of an inlet-engine installation.

However, before this conclusion can be generalized, data similar to those reported herein must be obtained with other configurations. In any event, cold-flow inlet stability data should be used with caution in predicting the stability of engine-inlet combinations. If data for the short cold pipe were to be applied to the engine-inlet configuration, the results would be slightly optimistic. On the other hand, if the inlet were tested with a long cold pipe the results would be quite pessimistic.

SUMMARY OF RESULTS

A supersonic inlet was tested with a J34 turbojet engine and with three cold-pipe configurations to determine their effects on the inlet stability characteristics. A comparison of the four configurations at a free-stream Mach number of 2.0 and an angle of attack of 0° showed the following:

1. Inlet stability data are affected by the ducting and positioning of the airflow regulating device behind the inlet.

2. A cold-pipe configuration having a length and volume equivalent to that represented by assuming the choke point occurs at the engine turbine gives very nearly the same inlet stability limit as that obtained with the engine-inlet configuration.

3. Increasing the volume and pipe-length-to-choke-point increased the cowl-lip-position parameter for complete buzz-free operation and decreased the initial buzz frequency at the cowl-lip-position parameter of 42.6°.

4. The change with configuration in the minimum subcritical stable mass flow below a cowl-lip-position parameter of 44° is, within the accuracy of the data, small.

5. Volume and pipe-length-to-choke-point for a cowl-lip-position parameter of 42.6° appeared to have a negligible effect on the inlet pressure-recovery - mass-flow variation.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, November 21, 1956

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1. Beheim, Milton A., and Englert, Gerald W.: Effects of a J34 Turbojet Engine on Supersonic Diffuser Performance. NACA RM E55I21, 1956.

2. Trimpi, Robert L.: A Theory for Stability and Buzz Pulsation Amplitude in Ram Jets and an Experimental Investigation Including Scale Effects. NACA RM L53G28, 1953.

3. Beke, Andrew, Englert, Gerald, and Beheim, Milton: Effect of an Adjustable Supersonic Inlet on the Performance up to Mach Number 2.0 of a J34 Turbojet Engine. NACA RM E55I27, 1956.

TABLE I. - COLD-PIPE CONFIGURATION CHARACTERISTICS

Pipe configuration	Length-to-choke-point, in.	Volume-to-choke-point, cu ft	Initial frequency, cps
Long	164	≈ 28.9	8
Medium	123	≈ 22.0	13.8
Short	83	≈ 12.2	16.9

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TABLE II. - ENGINE CONFIGURATION CHARACTERISTICS

Length to compressor inlet, in.	58
Length to compressor exit, in.	100
Volume to compressor exit, cu ft	≈14.2
Length to nozzle, in.	180
Volume to nozzle, cu ft	28
Initial frequency, cps	16.2

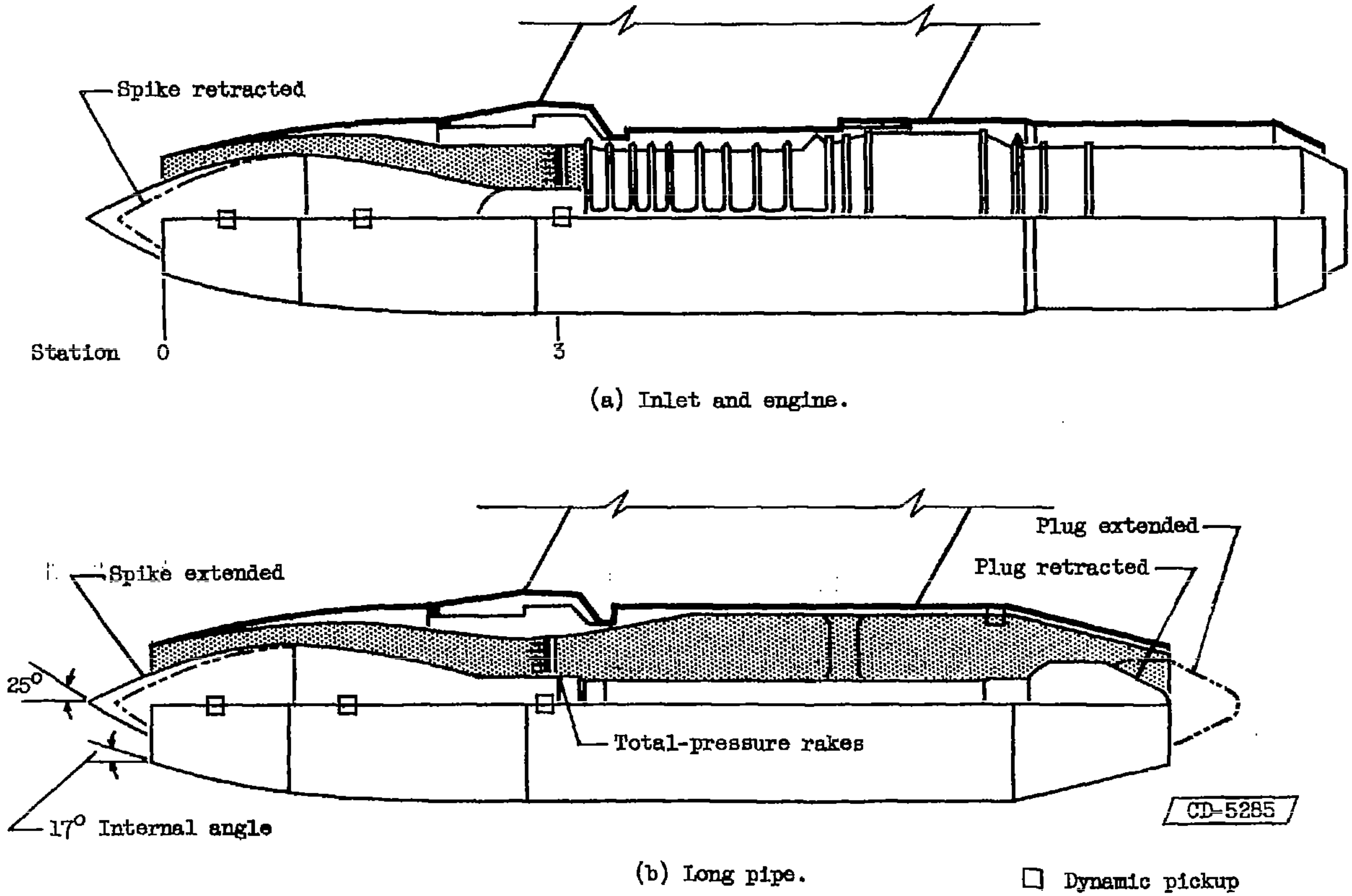
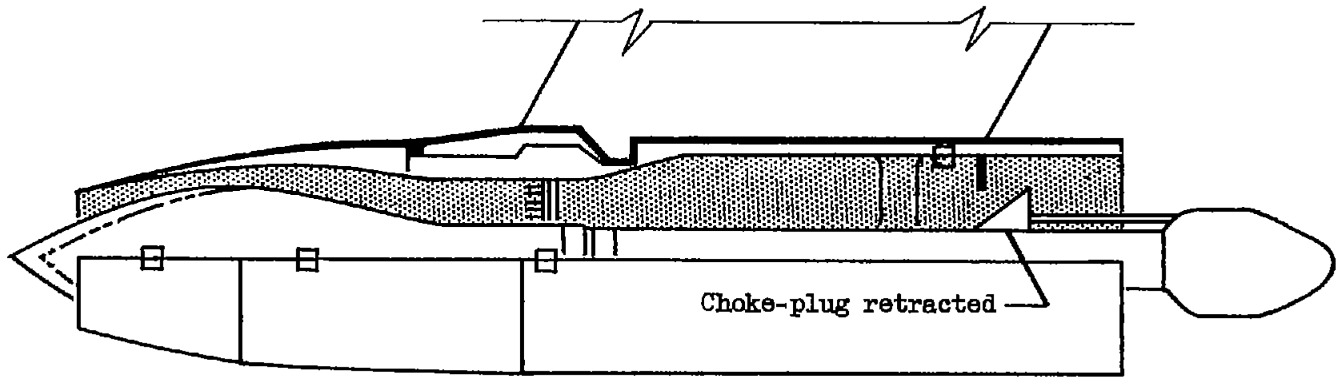
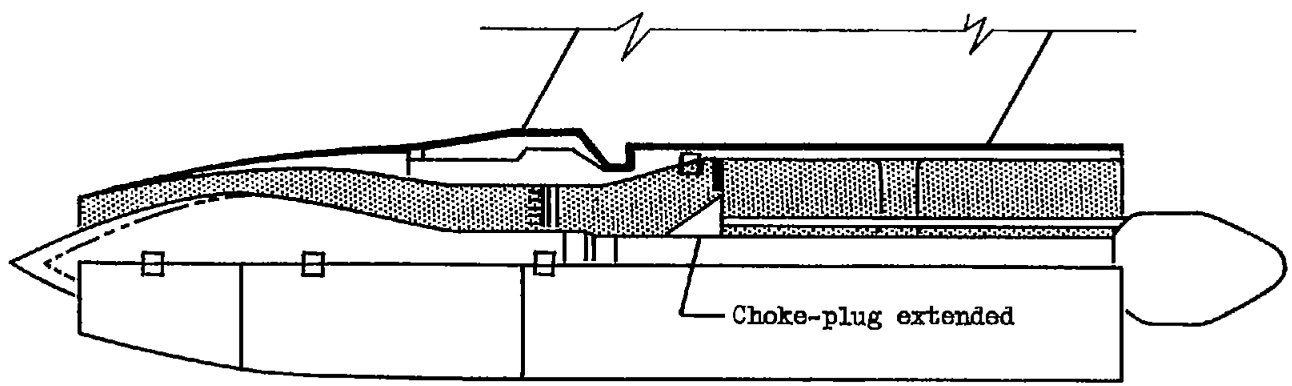


Figure 1. - Nacelle configurations.



(c) Medium pipe.



(d) Short pipe.

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□ Dynamic pickup

Figure 1. - Concluded. Nacelle configurations.

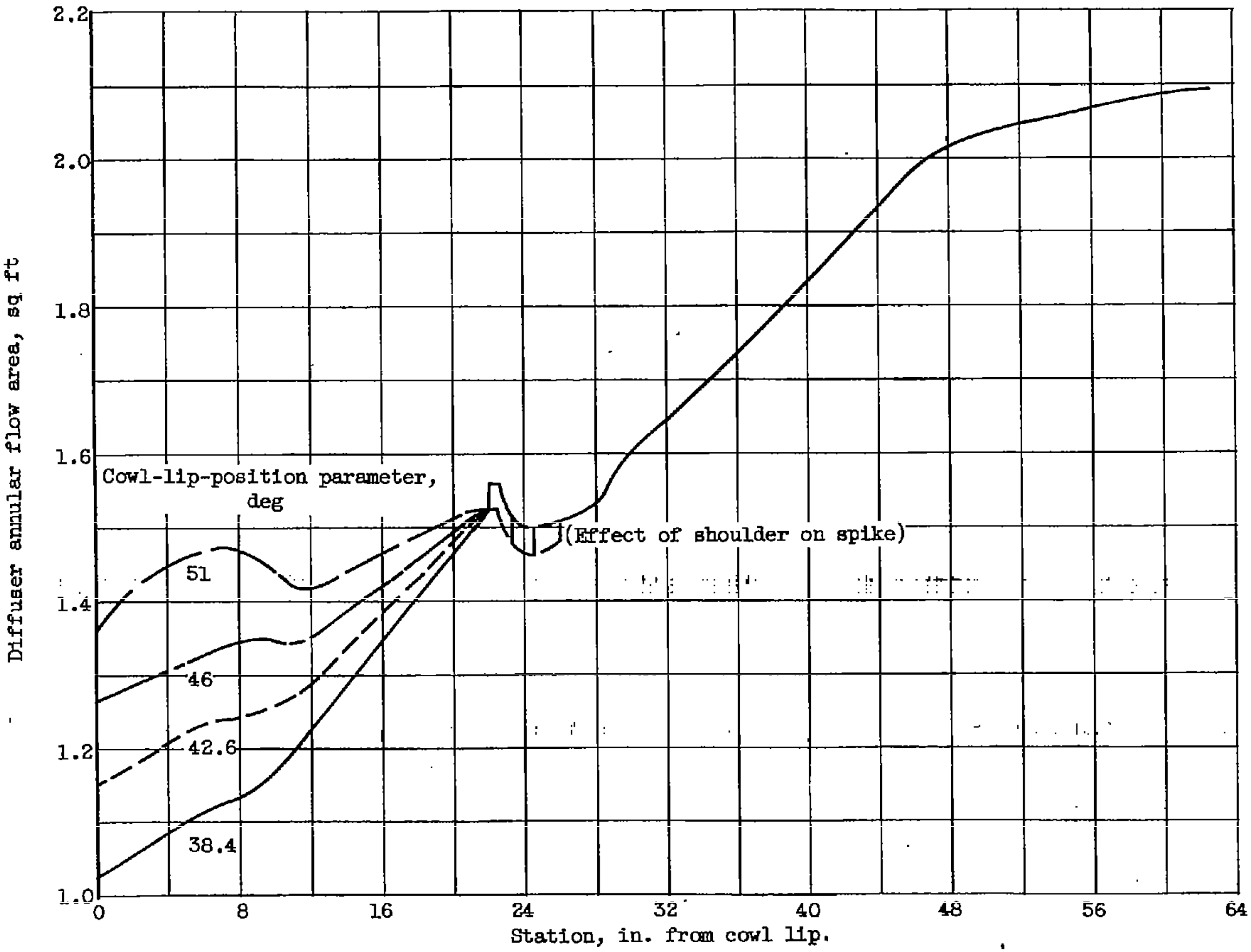


Figure 2. - Diffuser flow-area variation.

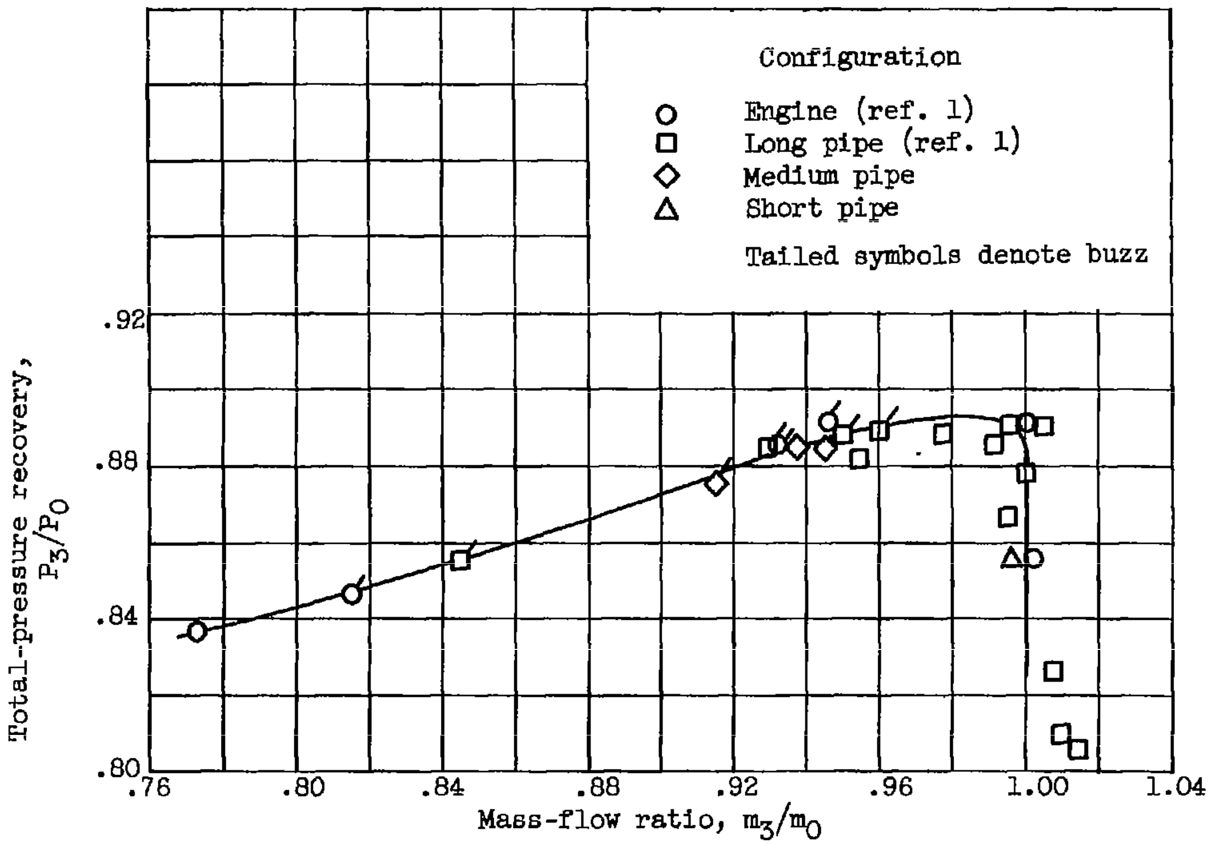
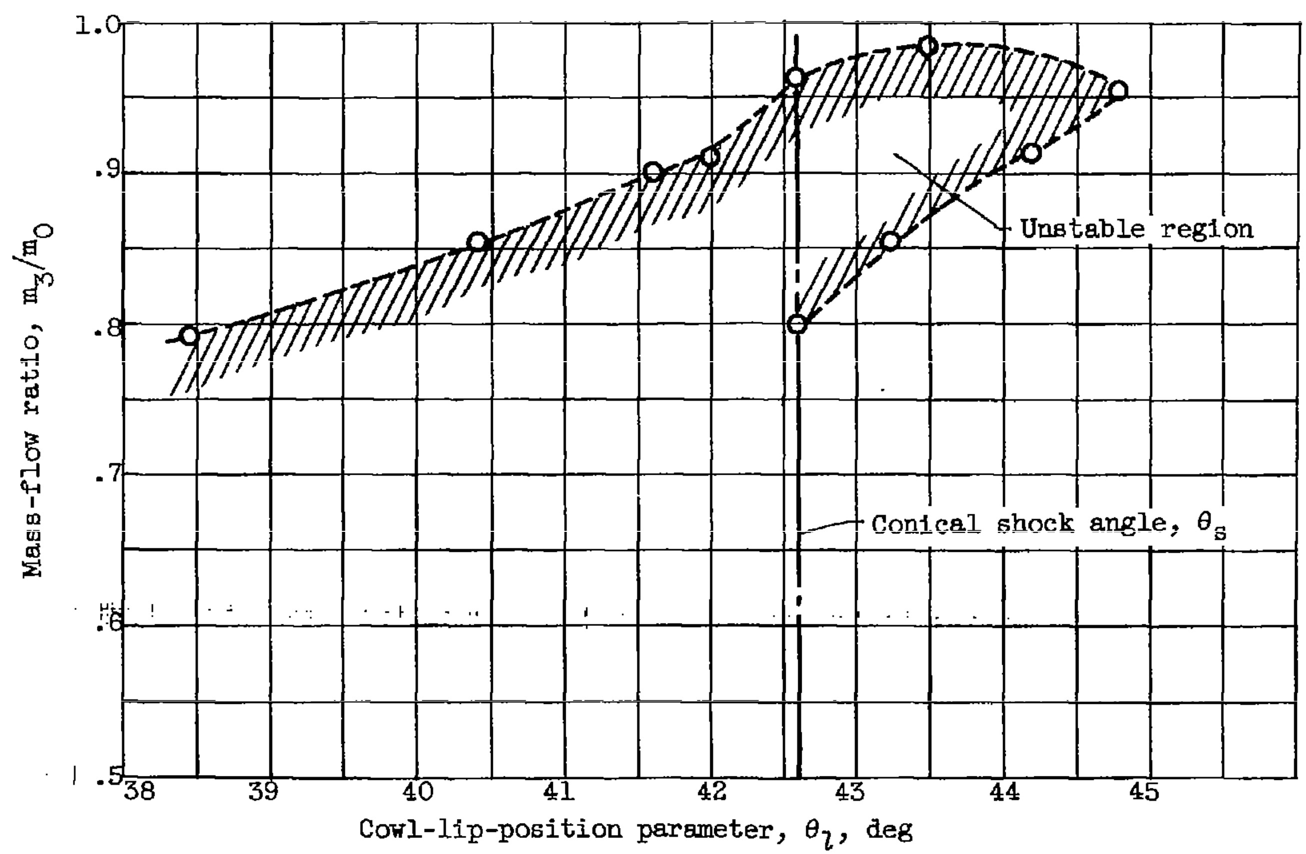
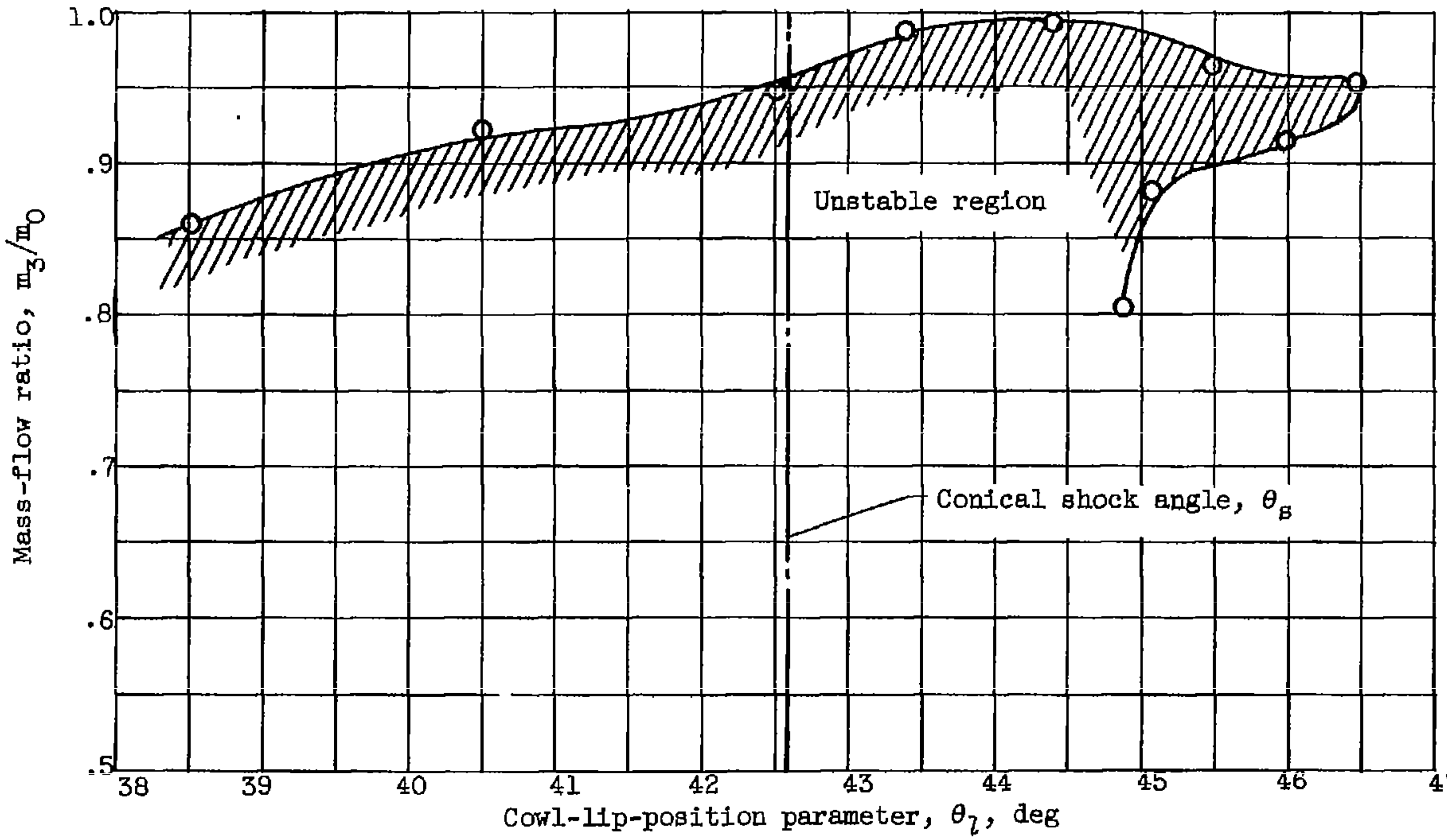


Figure 3. - Inlet performance at free-stream Mach number of 2.0 and angle of attack of 0°. Cowl-lip-position parameter, 42.6°. (The appropriate mass-flow coefficient was applied to ref. 1.)



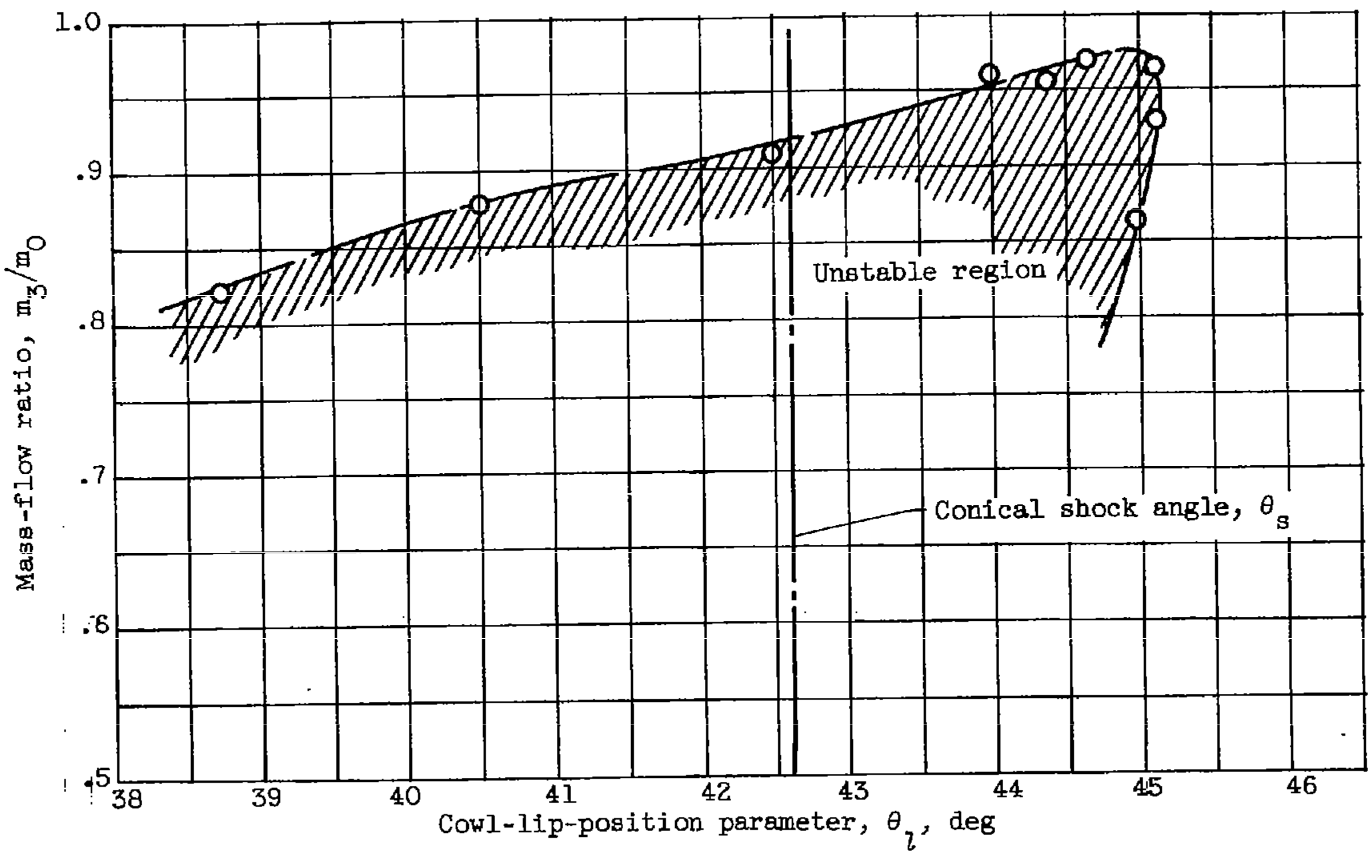
(a) Engine.

Figure 4. - Inlet subcritical stability limits for various configurations. Free-stream Mach number, 2.0; angle of attack, 0°.



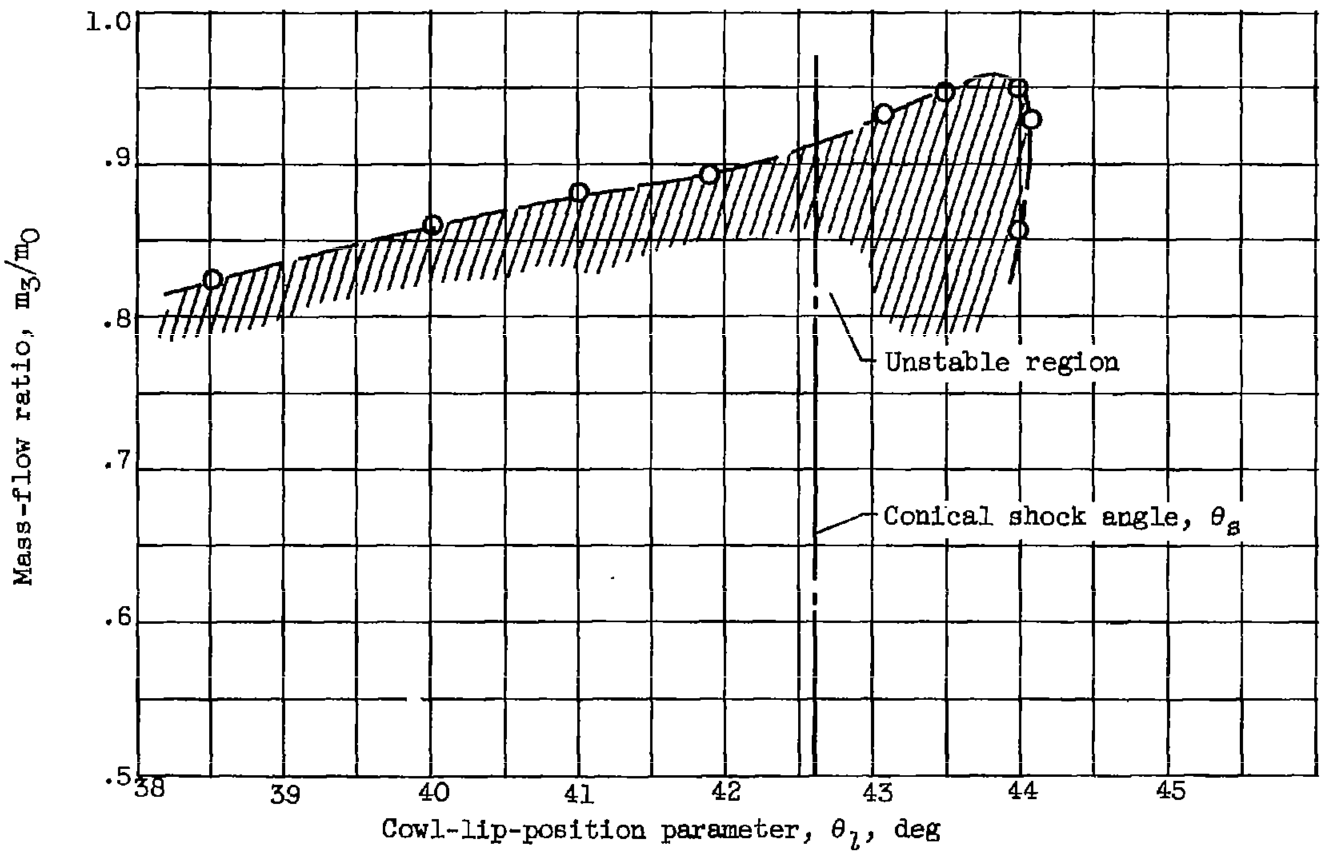
(b) Long cold pipe.

Figure 4. - Continued. Inlet subcritical stability limits for various configurations. Free-stream Mach number, 2.0; angle of attack, 0°.



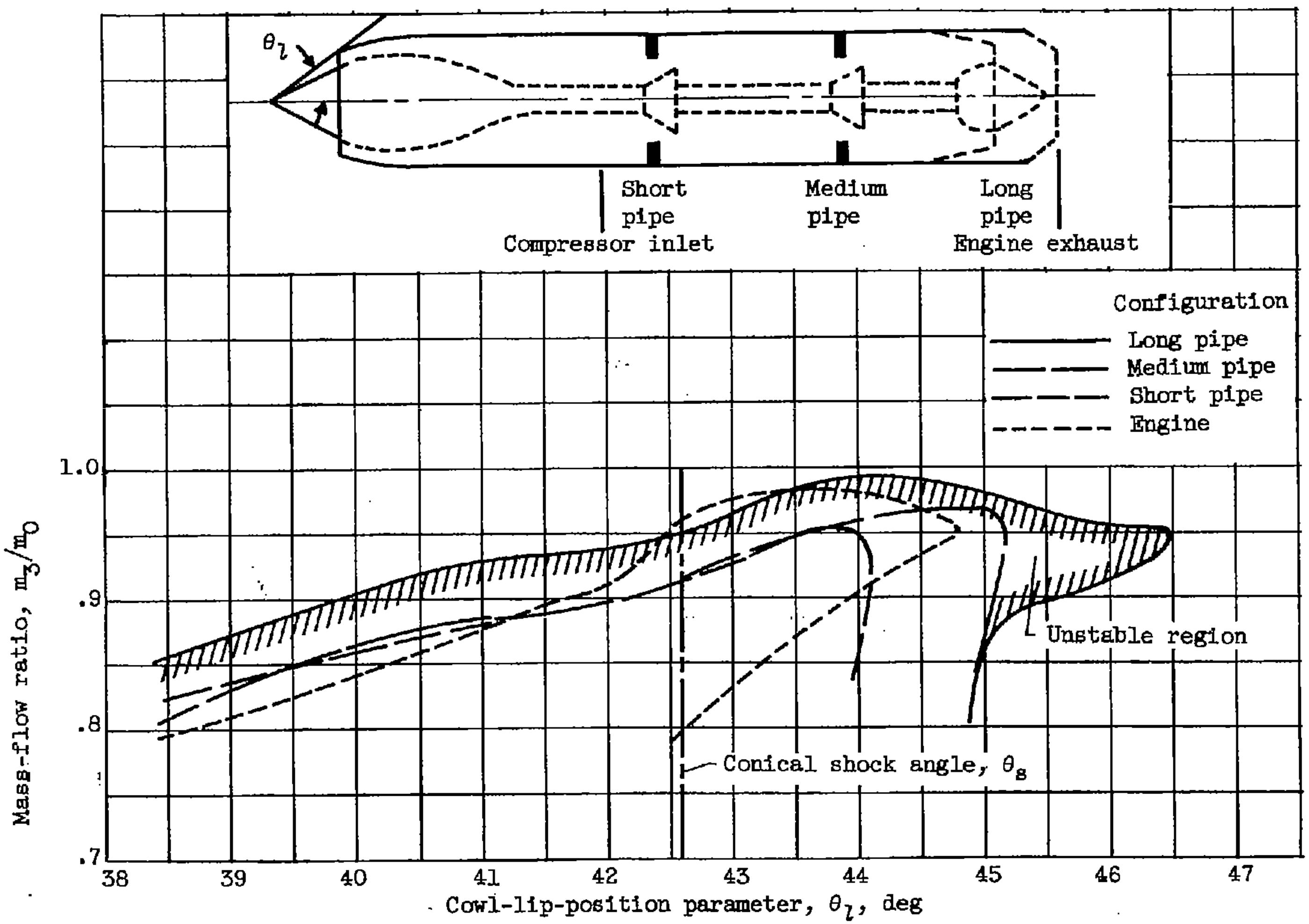
(c) Medium cold pipe.

Figure 4. - Continued. Inlet subcritical stability limits for various configurations. Free-stream Mach number, 2.0; angle of attack, 0°.



(d) Short cold pipe.

Figure 4. - Continued. Inlet subcritical stability limits for various configurations. Free-stream Mach number, 2.0; angle of attack, 0°.



(e) Summary of engine and cold-pipe configurations.

Figure 4. - Concluded. Inlet subcritical stability limits for various configurations. Free-stream Mach number, 2.0; angle of attack, 0°.